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RESEARCH MEMORANDUM

USE OF SUBSONIC DIFFUSER MACH NUMBER AS A SUPERSONIC-INLET CONTROL PARAMETER

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

USE OF SUBSONIC DIFFUSER MACH NUMBER AS A SUPERSONIC-INLET CONTROL PARAMETER

By Paul P. Whalen and Fred A. Wilcox

SUMMARY

A Mach number measured in the subsonic diffuser was used experimentally as the inlet control parameter of a bypass control system for an axisymmetric supersonic inlet operated in combination with a J34 turbojet engine at Mach numbers from 1.6 to 2.0. The control maintained the inlet in either critical or supercritical operation and, when set for critical diffuser operation, the control recovered from disturbances that placed the inlet in both subcritical buzz and supercritical operation.

A slotted-rake orifice gave a more representative value of subsonic diffuser Mach number than the single total-pressure probe used as a control input.

INTRODUCTION

Maintaining efficient operation of supersonic inlets over a range of flight speeds, ambient temperatures, and turbojet engine speeds with translating or variable-ramp compression surfaces or bypass air outlets is discussed in references 1 and 2. Methods for controlling such variable-geometry features by normal and oblique shock positioning are suggested in reference 3.

Control systems that depend on sensing shock position, however, often lose their usefulness at low supersonic flight speeds. With some inlets that have internal contraction, optimum performance over the speed spectrum may be obtained at a variety of normal-shock positions, thus making it difficult to use a fixed-shock-position sensor. Detached shocks from the cowl lip may interfere with the shock-sensing pressure signal, as in reference 4 at a free-stream Mach number of 1.6. In addition, because of the necessary location of the sensing elements at or near the cowl lip, shock-positioning controls have an inherently long dead time with respect to engine-imposed disturbances.

To avoid these difficulties, an alternative means of sensing the inlet operating condition can be provided by measuring the Mach number at a station in the subsonic diffuser. Experimentally observed results are presented of the application of this parameter to a bypass control system for a supersonic inlet operated in combination with a J34 turbojet engine. The tests were conducted in the NACA Lewis 8- by 6-foot supersonic wind tunnel at Mach numbers from 1.6 to 2.0.

SYMBOLS 4044

The following symbols are used in this report:

A_f compressor-rotor frontal area, 1.98 sq ft

M Mach number

P total pressure, lb/sq ft

p static pressure, lb/sq ft

$\frac{W_2\sqrt{\theta}}{\delta_3 A_f}$ corrected air-flow parameter, lb/(sec)(sq ft)

γ ratio of specific heats

δ total pressure at station 3 divided by NACA standard sea-level static pressure

θ stream total temperature divided by NACA standard sea-level static temperature

θ_l angle between axis of spike and line joining cone apex and cowl lip, deg

Subscripts:

0 free stream

2 diffuser station ahead of bypass, 28 in. downstream of cowl lip

3 diffuser station behind bypass, 58 in. downstream of cowl lip

SUBSONIC DIFFUSER MACH NUMBER AS BYPASS CONTROL PARAMETER

At a fixed flight condition, the Mach number at any selected station in the subsonic diffuser of a fixed-geometry inlet is a continuous single-valued function of the corrected air flow through the inlet. Optimum performance of the inlet occurs at a unique value of this Mach number. With a turbojet engine installed behind the inlet, this Mach number is determined by the engine air-flow requirements. The operating condition thus set by the engine may not be optimum for the inlet. The addition of a properly matched bypass provides a means of operating the inlet at the desired conditions as the engine air-flow requirements change.

The ratio of static to total pressure measured at a station in the subsonic diffuser ahead of the bypass provides a signal that is proportional to Mach number as given by the following equation:

$$\frac{p_2}{P_2} = \left[1 + \left(\frac{\gamma - 1}{2}\right) M_2^2\right]^{-\frac{\gamma}{\gamma-1}}$$

This pressure ratio can be used to position the bypass to maintain the diffuser Mach number at the desired value. This is accomplished by opening the bypass when the measured Mach number is lower than desired and closing when the Mach number is higher. Because the Mach number for optimum inlet performance will, in general, vary with flight Mach number; a schedule of desired control-station Mach numbers with flight Mach numbers may be necessary.

APPARATUS AND PROCEDURE

Experimental data were obtained for the bypass Mach number control on an engine-inlet installation in the Lewis 8- by 6-foot supersonic wind tunnel. A sketch of the nacelle and the control system is given in figure 1.

The J34 engine-inlet combination used in this investigation is described in reference 5. The supersonic inlet used had a translating 25° half-angle spike and an adjustable bypass operated by a servomechanism, which could spill a maximum of 20 percent of the engine air flow. To stay within the operating limits of the bypass, the spike position was set at an angle θ_l of 42°, 45°, and 42.6° at Mach numbers of 2.0, 1.8, and 1.6, respectively. Engine fuel flow was controlled manually.

Bypass air was bled through a series of longitudinal slots in the outer wall of the subsonic diffuser to a cavity between the diffuser wall and the nacelle skin, and then discharged to the free stream through a hinged bypass door in the nacelle skin. The bypass door was actuated by a hydraulic servomechanism. In response to an error voltage, a pilot valve metered high-pressure oil to the actuating cylinder. The pilot valve was positioned by the error voltage so that the rate of bypass travel was proportional to the error (servomechanism input) voltage, and the total bypass travel was proportional to the time integral of the error voltage. 4044

A static-pressure orifice and a single total-pressure probe at the control station (station 2, fig. 1, ahead of the bypass) were connected to pressure transducers. The voltage outputs of the transducers were amplified and fed into a dividing network and the quotient output voltage was compared with a reference voltage. The resultant error voltage was used to operate the bypass servomechanism.

Transient data were recorded by an optical-type oscillograph using transducers to measure pressures and a slide-wire indicator to indicate bypass position. Steady-state pressures were recorded by an automatic digital pressure recorder. Steady-state instrumentation was located near all transient instrumentation.

The behavior of the control was investigated both by manually displacing the bypass from its controlled setting and changing the fuel flow to the J34 turbojet engine.

Rakes of total-pressure probes and wall static orifices were located at both stations 2 and 3. The total-pressure probe used for the control was located 0.925 inch from the outer wall 30° from the vertical centerline. A slotted-orifice rake and a wall static-pressure orifice (fig. 2) were located at the same circumferential position 8 inches downstream of station 2. A rake of this type is described in reference 6. Unpublished tests of this rake show that it indicates the average duct total pressure within about 1 percent, even when very severe flow profiles are present.

RESULTS AND DISCUSSION

The steady-state performance of the inlet is shown in figure 3. The diffuser total-pressure recovery P_3/P_0 is given as a function of corrected inlet air flow $W_2\sqrt{\theta}/\delta_3 A_f$ based on the frontal area of the compressor rotor A_f (1.98 sq ft) and the diffuser total pressure. The data shown for the extreme values of air flow were obtained by replacing the engine with an exit plug to throttle the air flow. Inlet air flow is defined as the total air flow in the diffuser ahead of the bypass and is a function of the diffuser Mach number at station 2.

The control pressure ratio p_2/P_2 is presented in figure 4 as a function of corrected inlet air flow. Also shown on the figure is the theoretical control pressure ratio calculated from one-dimensional theory. This theoretical curve is independent of flight Mach number.

The large deviations from the theoretical value is the result of using a single tube to measure total pressure. Profile changes with corrected inlet air flow and with bypass position, as well as with free-
4044 stream Mach number, greatly affected this single total-pressure measurement.

The steady-state operation of the bypass control is indicated in figure 5, where steady-state operating points set by the control are superimposed on diffuser-performance and control-pressure-ratio curves. At each free-stream Mach number, the control reference voltage was manually adjusted to cause critical inlet operation as judged from schlieren observation. The fuel flow to the J34 turbojet engine was then manually varied and data were taken at various engine speeds. In a similar manner, data were taken for supercritical inlet operation.

At critical inlet operation, the control allowed a scatter as much as 5.8 percent in corrected inlet air flow as the engine speed was changed. However, the control held the pressure ratio p_2/P_2, within about 2 percent of the set value. The scatter in corrected inlet air flow was, therefore, primarily due to the double curvature of the control-pressure-ratio curve in the region of the set point. During supercritical inlet operation, where profile changes in the region of the signal total-pressure tube were small, the control maintained the desired corrected inlet air flow within about 0.7 percent. These results indicate the necessity of obtaining an accurate measurement of the average control total pressure.

Steady-state total-pressure data obtained with the slotted orifice rake are shown in figure 6 and compared with the average from the rakes at station 2. The data shown are for Mach numbers of 1.8 and 2.0 and include flow distortions $\frac{P_{2,max} - P_{2,min}}{P_{2,av}}$ of as much as 22.5 percent. The difference between the absolute levels of the two sets of data is attributed to the different flow areas at station 2 and at the location of the slotted-orifice rake. The signal from the slotted-orifice rake is a continuous function of the inlet corrected air flow and, with such a signal, it should be possible to improve the operation of the control and to reduce the scatter in the operating point set by this control system.

Two traces indicating the potentialities of this control system are shown in figure 7. Both traces were obtained at a free-stream Mach number of 2.0 with the inlet operation initially critical. In figure 7(a) the bypass was manually closed to cause subcritical inlet operation. The compressor-inlet total-pressure trace shows that the inlet was in the "buzz region." Turning on the control brought the inlet out of buzz within 5 cycles and returned the bypass to the steady-state controlled position in about 0.8 second.

In figure 7(b) the inlet operation was initially critical and the 4044
bypass was manually opened to cause supercritical inlet operation. Turning on the control initiated a rapid corrective action, causing the bypass to overshoot its original position followed by a slow return to the position for critical inlet operation. The control action in this case again required approximately 0.8 second.

No attempt was made in this preliminary study to determine loop gains for optimum control response, because of the irregular nature of the control signal available. However, this control system should have an inherently fast response because of the proximity of the sensing elements to the bypass in a region of low local Mach number.

CONCLUDING REMARKS

In an investigation of a supersonic-inlet turbojet engine installation in the NACA Lewis 8- by 6-foot supersonic wind tunnel, the ratio of static to total pressure representing the Mach number in the subsonic portion of the diffuser was used as a parameter for bypass control. The control recovered from disturbances placing the inlet in both subcritical buzz and supercritical operation.

An advantage of this type of control parameter is that the schedule can be arranged to operate the inlet with the normal shock at any desired position. The low value of dead time which can be achieved by locating the sensing station near the bypass should also prove advantageous.

In addition, it was found that a slotted orifice rake gave a more representative value of subsonic diffuser Mach number than the single total-pressure probe used in the control system.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, June 15, 1956

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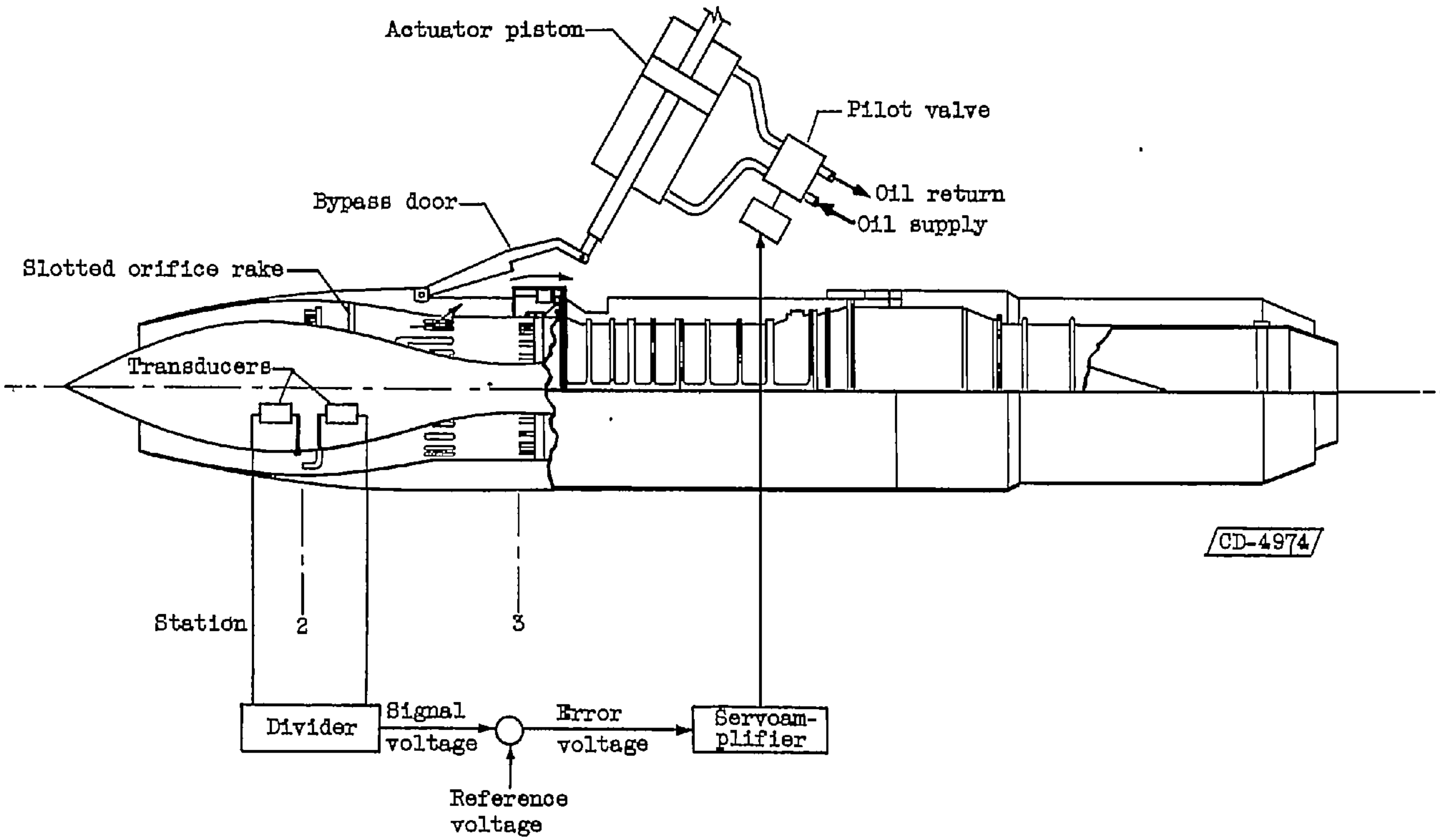

Figure 1. - Schematic diagram of J34 turbojet engine-inlet installation.

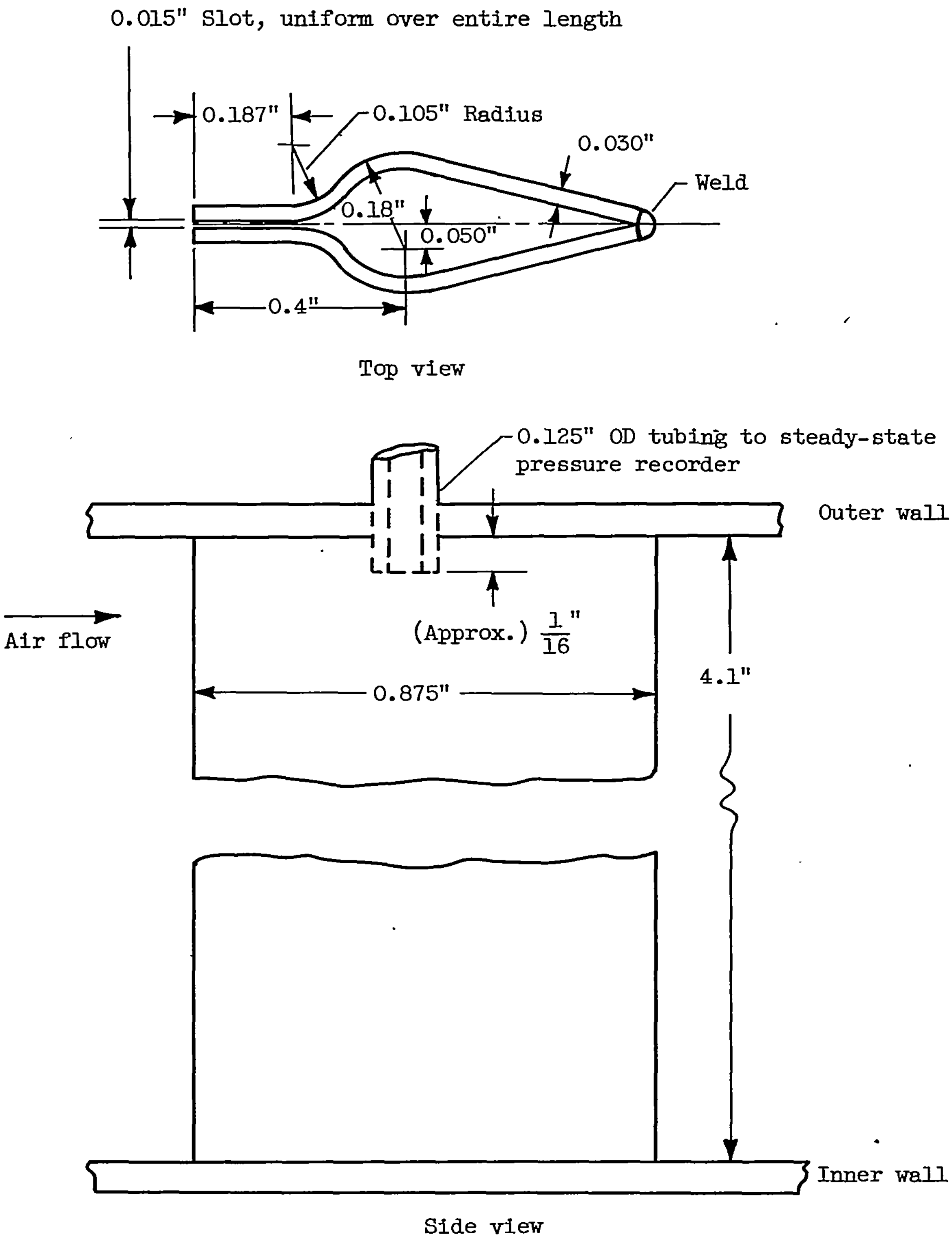

Figure 2. - Details of slotted orifice rake.

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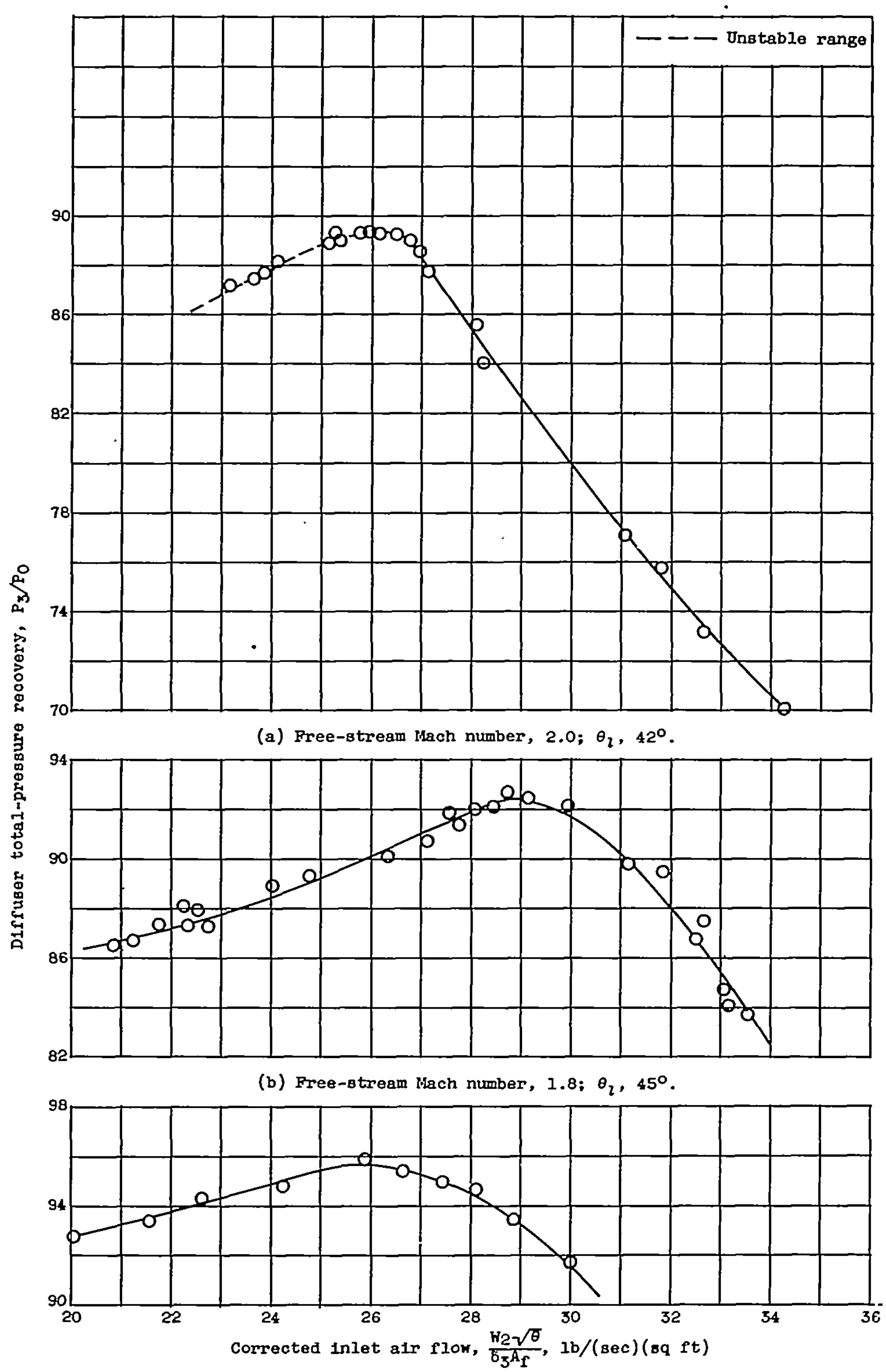

(a) Free-stream Mach number, 2.0; θ_l, 42°.

(b) Free-stream Mach number, 1.8; θ_l, 45°.

(c) Free-stream Mach number, 1.6; θ_l, 42.6°.

Figure 3. - Steady-state inlet performance.

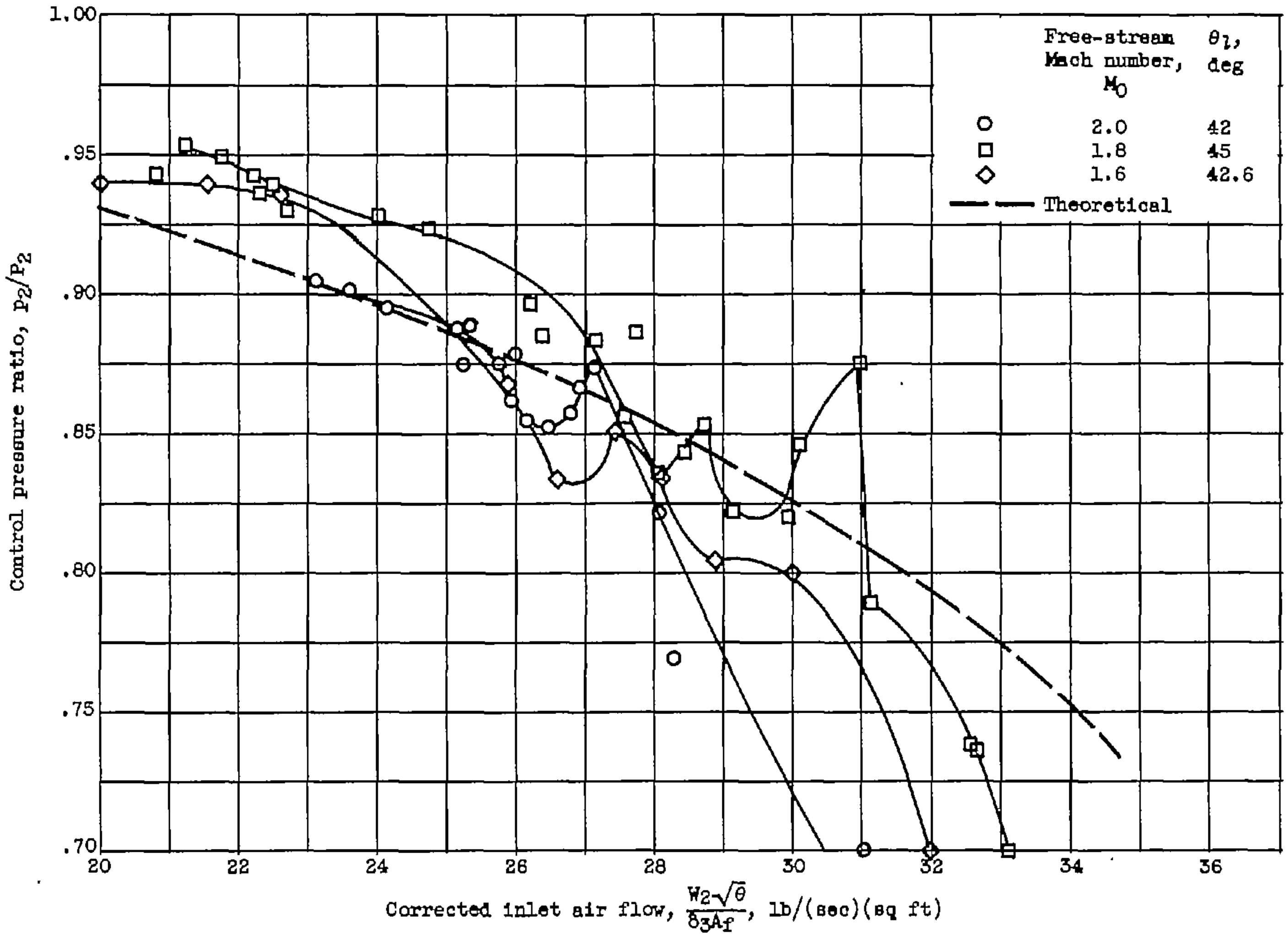

Figure 4. - Variation of control pressure ratio with corrected inlet air flow.

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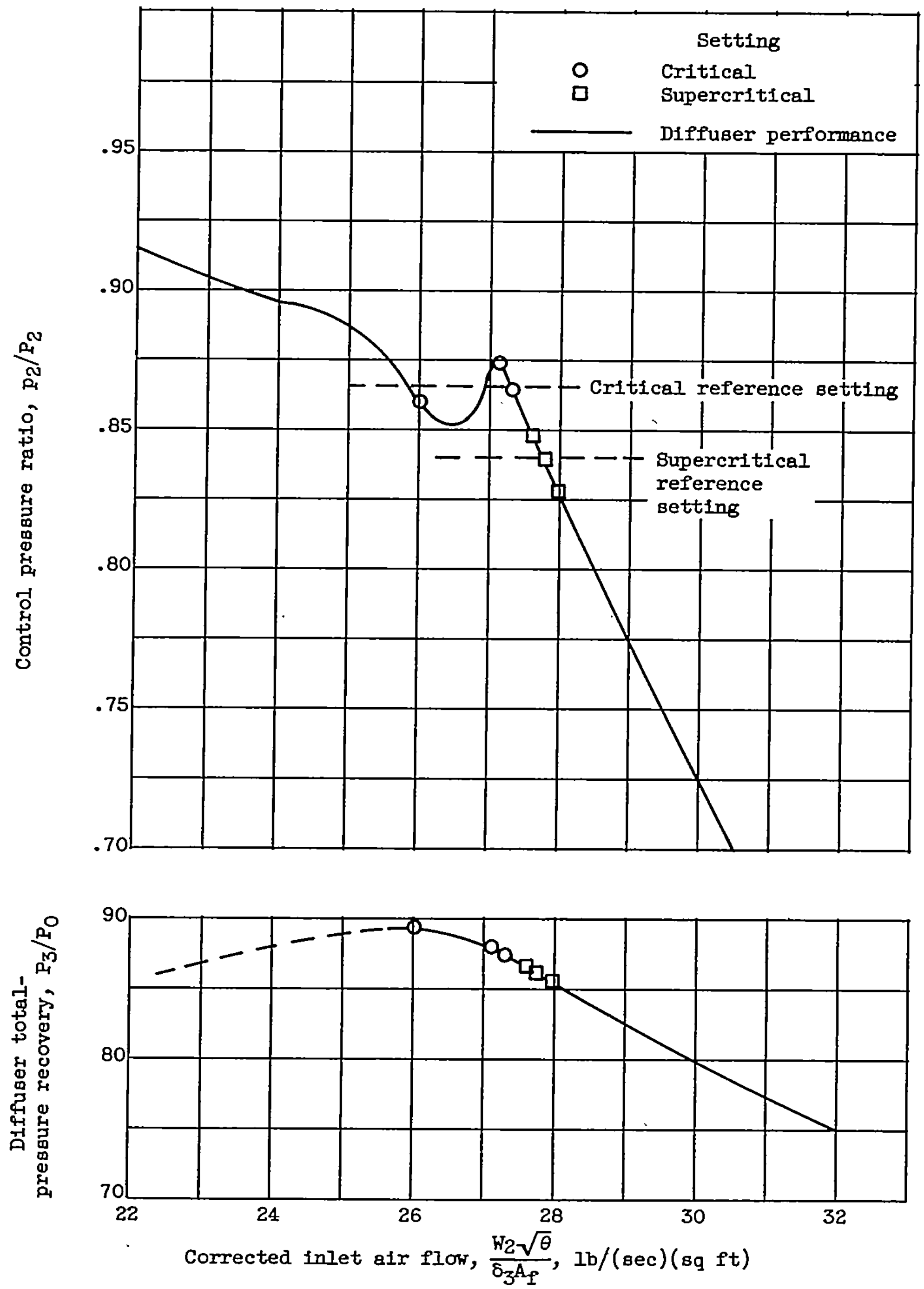

(a) Free-stream Mach number 2.0; engine speed, 10,516 to 11,370 rpm.

Figure 5. - Steady-state bypass control operation.

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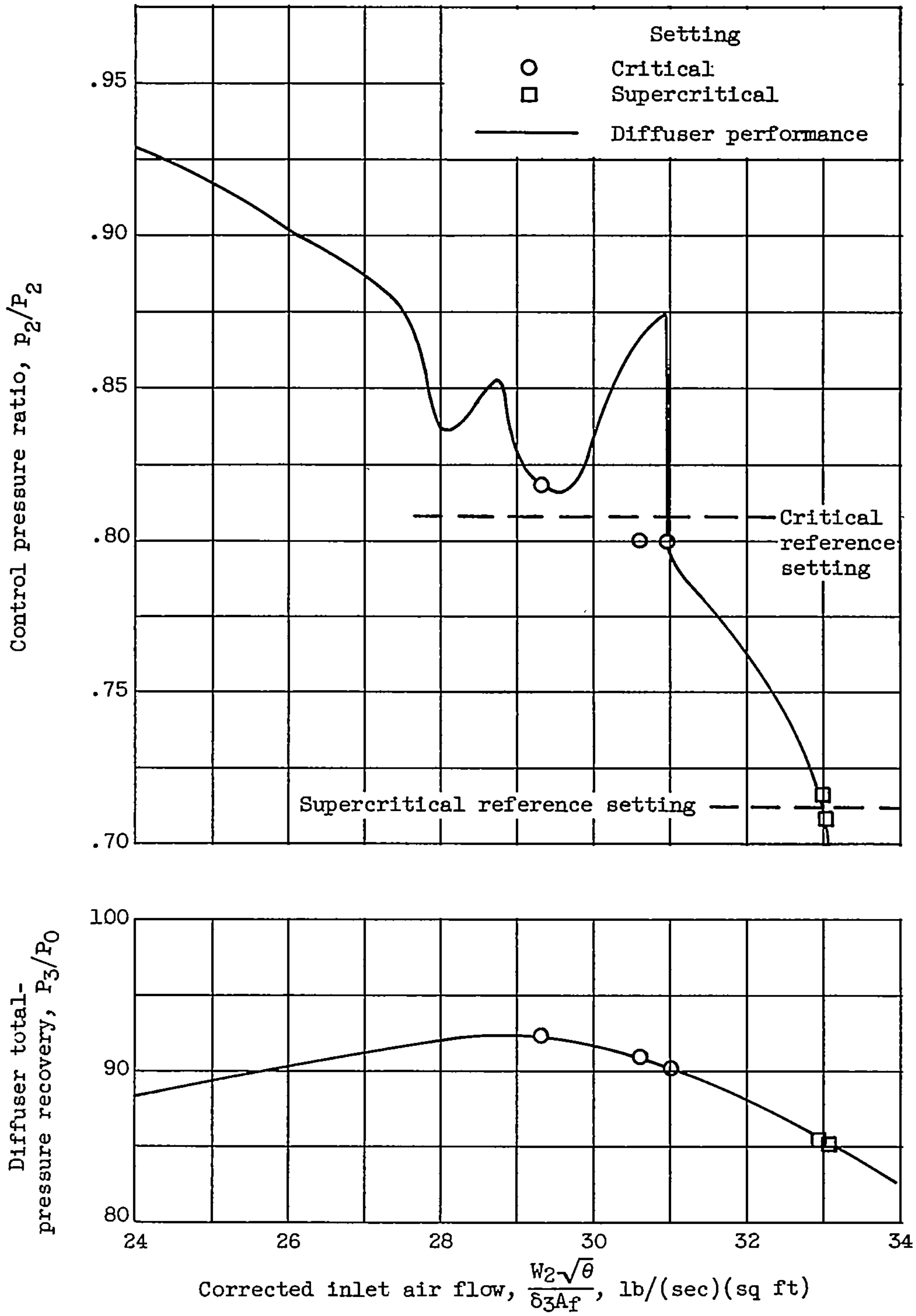

(b) Free-stream Mach number, 1.8; engine speed, 11,290 to 12,453 rpm.

Figure 5. - Continued. Steady-state bypass control operation.

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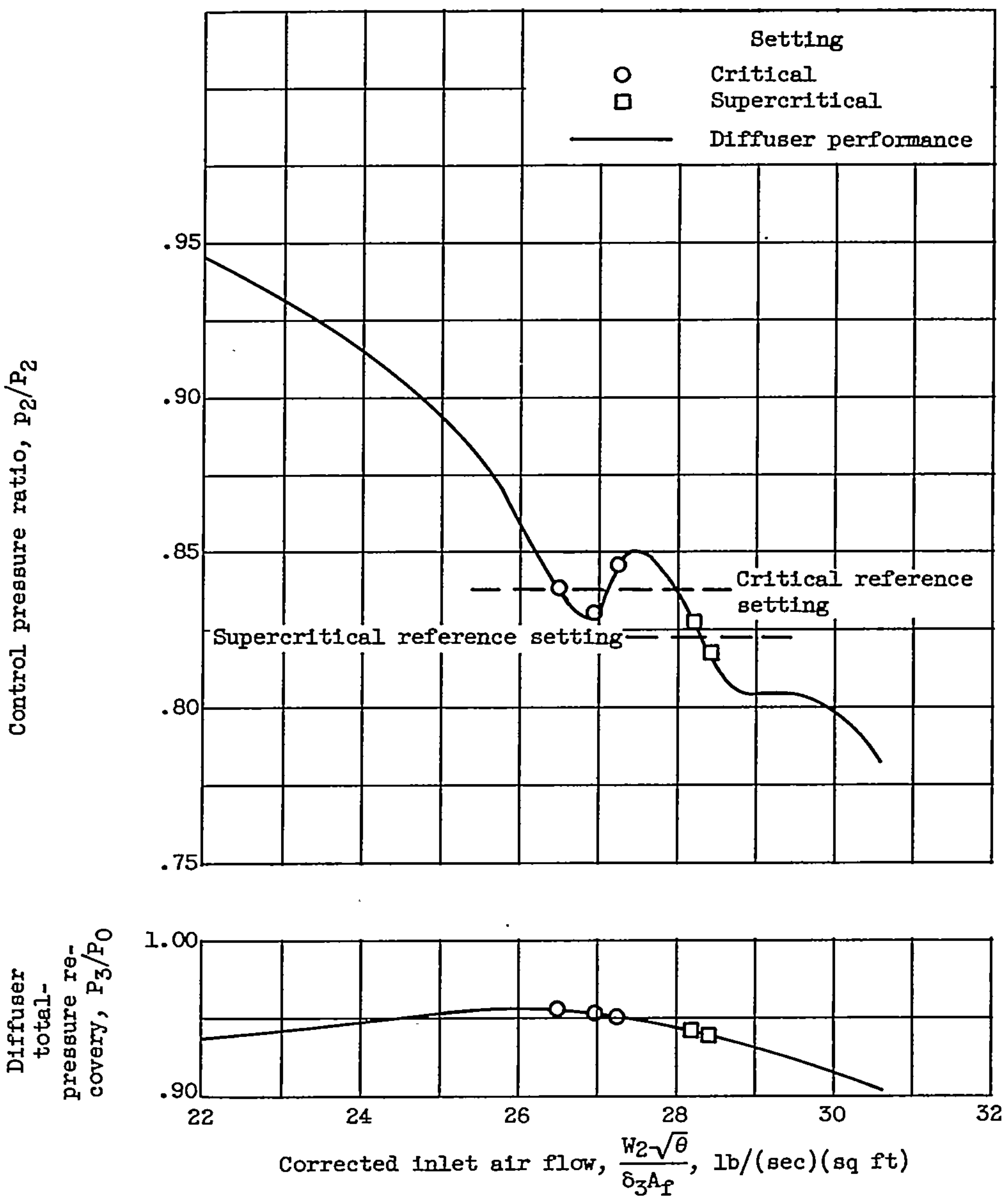

(c) Free-stream Mach number, 1.6; engine speed, 10,005 to 11,346 rpm.

Figure 5. - Concluded. Steady-state bypass control operation.

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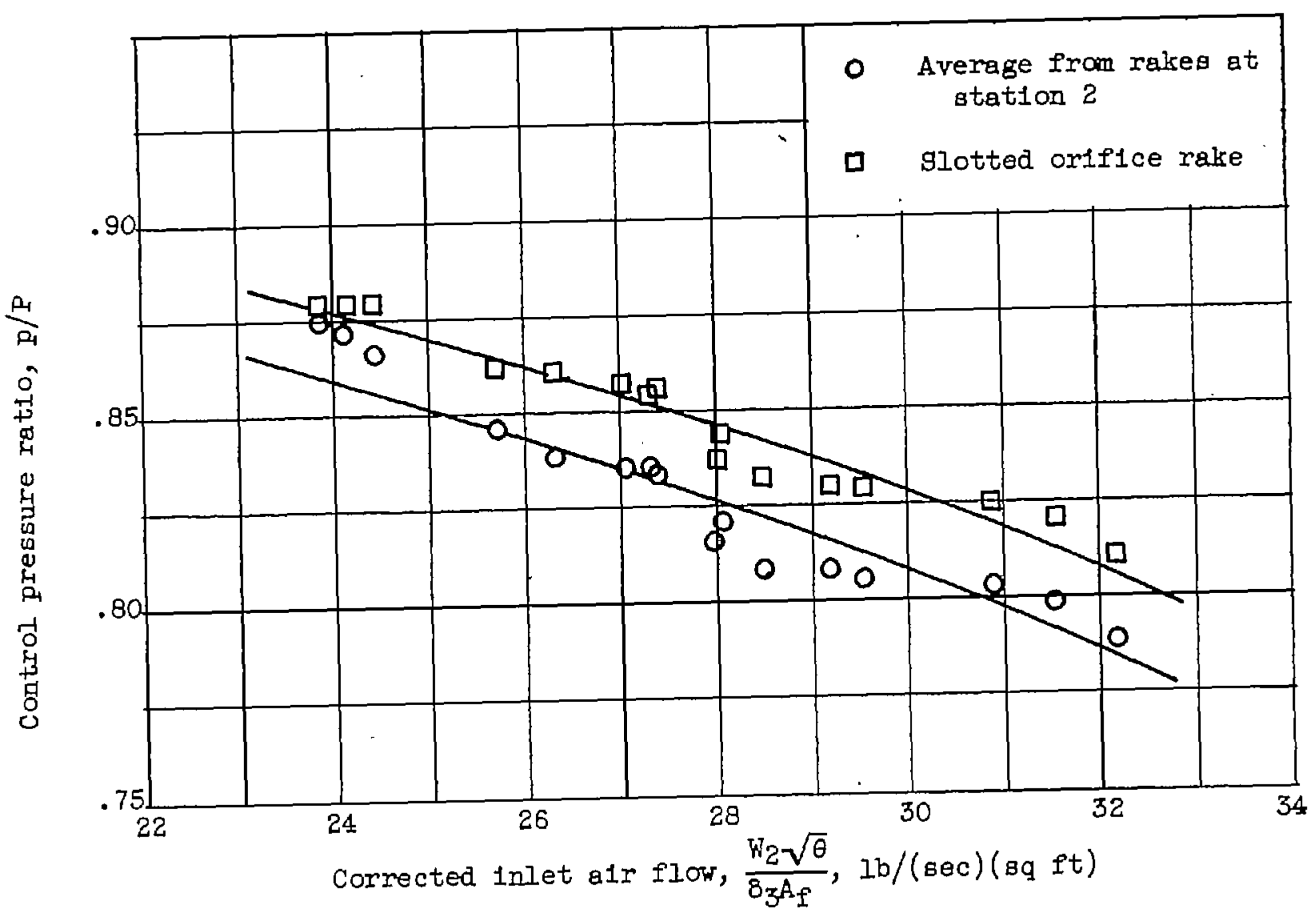

Figure 6. - Pressure ratio from slotted-rake orifice for free-stream Mach numbers of 1.8 and 2.0. Maximum flow distortion, 22.5 percent.

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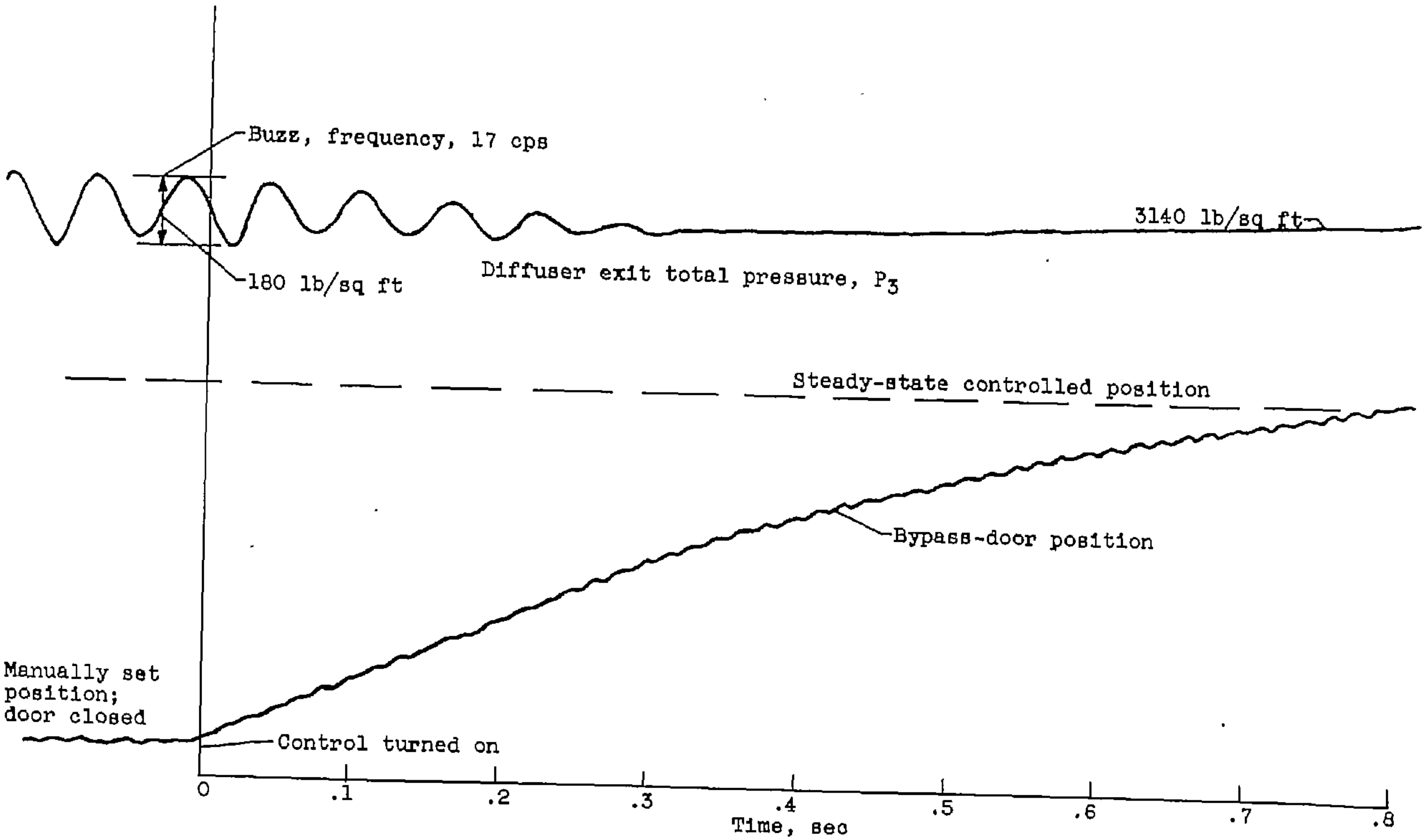

(a) Recovery from subcritical inlet operation; free-stream Mach number, 2.0; θ_l, 42.6°.

Figure 7. - Response of control to manually disturbed door position.

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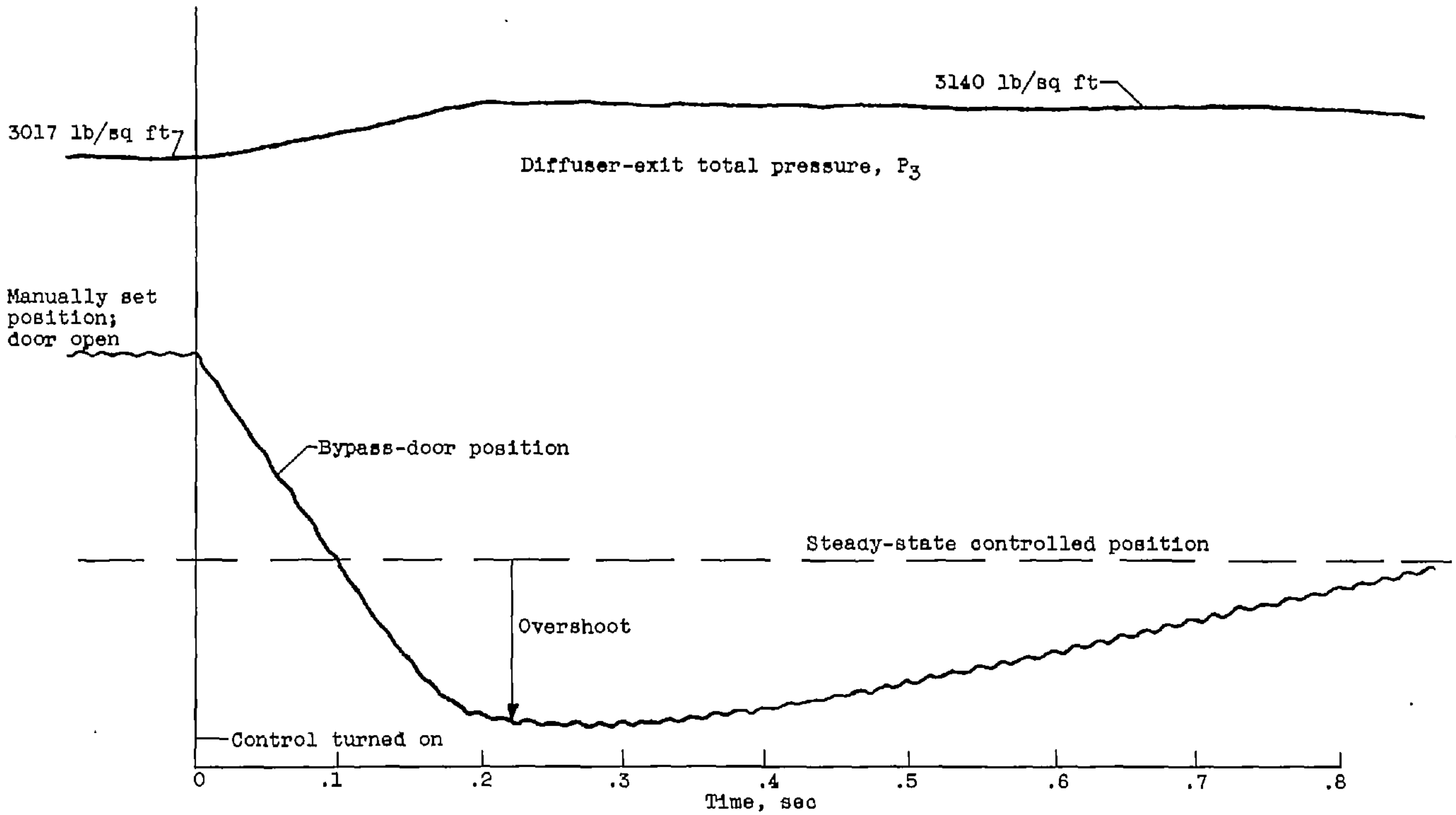

(b) Recovery from supercritical inlet operation; free-stream Mach number, 2.0; θ_l, 42.6°.

Figure 7. - Concluded. Response of control to manually disturbed door position.

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